Turbulence regime near the forest floor of a mixed broad leaved/Korean pine forest in Changbai Mountains

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Abstract: The measurement and observation for this study were carried out by using a three-dimensional (*u, v, w*) Sonic anemometer (IAP-SA 485), at Forest Ecosystem Opened Research Station of Changbai Mountains (128°28'E and 42°24' N, Jilin Province, P. R. China) in August 2001. The basic characteristics of turbulence, such as turbulence intensity, atmospheric stability, time scales, and convection state, near the forest floor were analyzed. It is concluded that the airflow near forest floor is characterized by high intermittence and asymmetry, and the active and upward movement takes the leading position. Near forest floor, the vertical turbulence is retained and its time scale and length scale are much less than that of *u, v* components. The eddy near forest floor shows a flat structure and look like a 'Disk'. Buoyancy plays a leading role in the generation and maintenance of local turbulence

Keywords: Forest floor; Velocity statistics; Atmospheric stability; Convection states
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Introduction

By recent research, the carbon dioxide flux in soil is considered as a second important project only to the gross photosynthesis (Raich and Schlesinger 1992). For this reason, an accurate measurement of soil contributions to net exchange of carbon in an ecosystem is of significance to estimation of the seasonal and annual carbon budgets of terrestrial ecosystems (Law *et al.* 1999). K-theory provides an alternative to eddy correlation (Baldocchi and Meyers, 1991) and chamber (Keller *et al.* 1986;Ivan *et al.*, 2000) techniques in measuring fluxes of heat, water and trace gases from forest floor. It requires less demanding measurements than eddy correlation technique and can also provides good spatial representative that cannot be easily achieved by the chamber technique. However, much research work and detail analysis should be done to determine how the eddy diffusivity is related to stand structure and turbulence regimes (Lee and Black 1993).

During the past two decades, many researches had been carried out on turbulence processes around canopy (Allen, 1968; Denmead *et al.* 1985; Shaw 1985; Shaw and Seginer 1987; Amiro and Davis 1988; Baldocchi and Meyers 1988; Amiro 1990; Lee and Black 1993; Zelger *et al.* 1997), but less attention were paid to that near forest floor. This is because of that the traditional theory of turbulence process hold the view of that forest floor had less contribution to heat and momentum exchanges between forest and atmosphere.

Mixed broad leaved-Korean pine forest is the typical zonal vegetation in the North China. Over the past decades, great deals of researches have been conducted on the effects of microclimate and water for this typical forest. Up to date, however, no report has been found on turbulence exchange around the mixed broadleaved/Korean pine forest. Based on the data measured in 2001, the authors analyzed the basic characteristics of turbulence, e.g. turbulence intensity, atmospheric stability, time scales, convection states, etc., near the forest floor of the mixed broadleaved/Korean pine forest in Changbai Mountains. This paper aims at providing theoretical basis for accurately estimating the carbon dioxide flux in soil

Methods

Site location and data collection

The measurement and observation for this study were carried out in No. 1 Plot at Forest Ecosystem Opened Research Station of Changbai Mountains (128°28'E and 42°24' N, Jilin Province, P. R. China), Chinese Academy of Sciences, in August 2001. The primeval forest is composed of conifer and deciduous-mixed forest. Around the observation site it is mixed broadleaved/Korean pine forest, typical vegetation in this area, with an average tree height of 26 m.

A 62.8-m-tall meteorological tower is located at the site with an altitude of 738 m above sea level. On the tower, a three-dimensional (*u, v, w*) sonic anemometer (IAP-SA485), which was made by the Institute of Atmospheric Physics,

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Chinese Academy of Sciences, was mounted at a height of 3 m, and the sensor head was installed at a upwind height of 2 m, keeping a distance of 0.5 m or more from nearest vegetation element to prevent reflection of the sonic signal. The data was sampled at a frequency of 16 Hz. Raw data were sliced into 30-min segments for subsequent analysis.

Data preprocessing

Coordinate rotation was made to interpret properly the measurements of the eddy correlation unit. The new coordinate system was defined, as that *u* was the stream-wise component of the velocity vector, *v* the lateral component of the vector, and *w* the component of the vector normal to the ground surface.

Data analysis

Local atmospheric stability was characterized by the $\varsigma = z/L$, where *L* is Monin-Obukov length, and it is calculated by ς

$$L = \frac{-\overline{\theta_v} u_*^3}{kg\overline{w'\theta'_v}}, \tag{1}$$

Here *k* is Von Karman constant (assumed=0.4), *g* is the acceleration velocity due to gravity, θ is the potential temperature, and u_* is the frication velocity from

$$u_* = \left(\overline{u'w'}^2 + \overline{v'w'}^2\right)^{1/4} \tag{2}$$

Turbulence intensity $I_{u,v,w}$ were calculated as

$$I_{u,v,w} = \frac{\sigma_{u,v,w}}{\overline{u}}, \tag{3}$$

where, $\sigma_{u,v,w}$ is the standard deviation of *u*, *v*, and *w*, $\overline{u}$ is the average horizontal velocity (m/s).

Skewness, Sk, was calculated as

$$Sk_x = \overline{x'^3}/\sigma_x^3; \tag{4}$$

where, *x* represents *u*, *v*, *w*.

Kurtosis, Kurt of velocity components were calculated as

$$Kr_x = \overline{x'^4}/\sigma_x^4, \tag{5}$$

Eulerian time scales *T*, were estimated as

$$T = \int_0^\infty R(\xi)d\xi \tag{6}$$

where $R(\xi)$ is the Eulerian autocorrelation function at time lag ξ, $R(\xi) = \frac{\overline{x'(t)\cdot x'(t+\xi)}}{\sigma_x^2}$, where *x* stands for *u* or *v* or *w*.

Following Amiro (1990), Length scales were defined as

$$L = \sigma_{u,v,w} T_{u,v,w} \tag{7}$$

When the airflow within canopy is in free convection condition, free convection velocity can be defined as

$$w_* = \left(\frac{gz}{\theta_v}\overline{w'\theta'_v}\right)^{\frac{1}{3}} \tag{8}$$

Results

Daily pattern of atmospheric stability near forest floor

Atmospheric stability is one of the most important factors controlling the exchange of matter and energy. We use Local atmospheric stability parameter, ς, to analysis the diurnal pattern of the atmospheric stability near the forest floor. To show the pattern more clearly, we classified the atmospheric stability into five classes (Table 1). Daily pattern of local atmosphere stability near forest floor was shown in Fig. 1. From 6:30 to 9:00, as the floor and canopy of the forest received solar radiation in-phase; the local stratification is unstable. With increasing of solar azimuth angle, solar radiation radiating to the forest floor is reduced by canopy, heat is transferred downward, and an inversion developed near the floor. During the nocturnal period, canopy and floor became cooling for the loss of long-wave radiation, but the soil temperature lowed more slowly due to the existence of dense canopy, as a result, the heat is transferred upward, and atmosphere became unstable. Along with cooling, there was a strong inversion near floor before dawn. For the existence of canopy, local atmosphere stability was unstable once in a while.

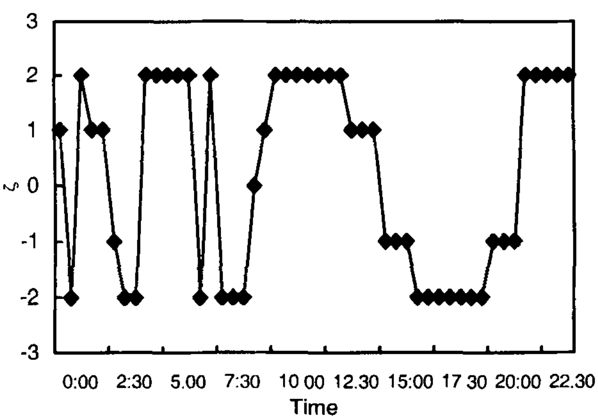

Fig. 1 Daily pattern of atmospheric stability at a height of 3 m near the forest floor of a mixed broad leaved/Korean pine forest in Changbai Mountains

Table 1. Classification of atmospheric stability

Stability class	ς range	Indicator
Very Stable	$\varsigma > 0.25$	2
Stable	$0.05 < \varsigma \leq 0.25$	1
Neutral	$-0.05 \leq \varsigma \leq 0.05$	0
Unstable	$-0.05 > \varsigma \geq -0.2$	-1
Very Unstable	$\varsigma < -0.2$	-2

Turbulence density

The Statistics of turbulence intensity at a height of 3 m were listed in Table 2. The average turbulence intensity of I_u approximately equaled to that of I_v, but I_w was remarkable lower than both I_u and I_v. This implies that vertical turbulence near the forest floor was strongly restrained. The eddy here looks like a 'Disk'. The values of I_u and I_v we measured are within the value range (0.64-2.3) that were measured previously by Baldocchi and Meyers (1988), Allen (1968), Amiro (1990), Shaw *et al.* (1988), and Lee and Black (1993) at the place near the floor of forests with an open trunk space, but they are smaller than the value range (1.7-5.7) that were measured by Moritz (1989), and Amiro (1990) in more dense stands. The I_w value we observed is lower than that observed by others.

Table 2: Statistics of turbulence intensity at a height of 3 m

Items	Average	Variance	Min.	Max.
I_u	0.746	0.124	0.215	1.752
I_v	0.718	0.096	0.189	1.335
I_w	0.249	0.014	0.085	0.614

Convection State

Using the method provided by Jacobs et al. (1994), we classified the convection state under canopy approximately into three types:

Free convection: $Gr > 16\mathrm{Re}^2$

Forced convection: $Gr < 0.1\mathrm{Re}^2$

Mixed convection: $16\mathrm{Re}^2 < Gr < 0.1\mathrm{Re}^2$.

Here *Gr* is Grashof Number that can describe buoyancy, and Re is Reynolds number.

Fig.2 Showed the diurnal variation of the ratio of Gr/Re^2 of airflow near forest floor. It can be seen that during daytime Gr/Re^2 lied in the range of 0.1-16, which indicated the flow near forest floor was in the mixed convection state; while during nighttime Gr/Re^2 was greater than 16 except for some occasions, which indicated that air flow was in the free convection state. Buoyancy may be the dominant factor controlling turbulence.

Experimental studies showed that convection velocity *w·* was greater than frication velocity *u·* for free convection conditions, but less than u· for forced and mixed convection conditions (Zelger *et al.* 1997). Our calculation give evidence to this remark for mixed convection state, but it need to be tested under free convection state (Fig. 3).

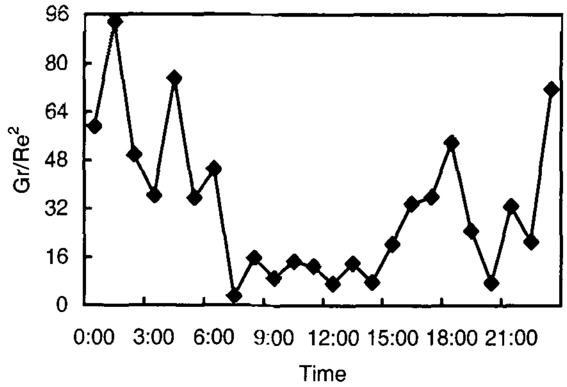

Fig.2 Dynamic convection states near forest floor

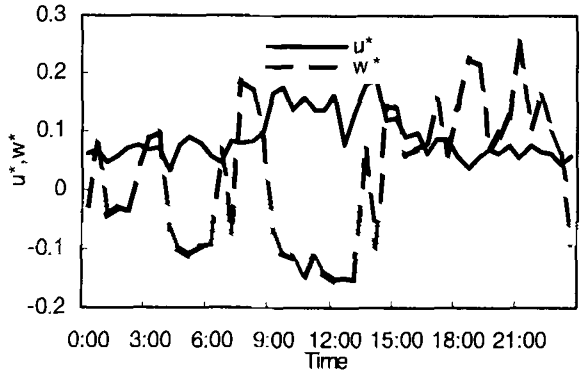

Fig. 3 Diurnal Patterns of friction velocity, *U·*, and free convection velocity scale, *W·*

Skewness and Kurtosis

Skewness expresses the degree of asymmetry of a probability distribution. The asymmetry nature of airflow can affect the release and deposition of pollen and spores (Aylor, 1991). Since airflow in the forest canopy was occasionally interrupted by large-scale downward movements (called 'Sweep'), *u* was positively skewed and *w* was negatively skewed around canopy (Shaw and Seginer 1987). Skewness of the *w* component was almost positive for all runs excepted in the dawn, implying active upward motions. This seemed to contradict the general picture but to be as similar as the results of Lee and Black (1993). There was not obviously daily pattern for Skewness of all velocity components. Pattern of *u* was close to mirror image of that of SK_w.

Krtosis is a measurement of peakness or flatness of a probability distribution, with a value of 3 for Gaussian distributions. Experimental studies have showed airflow in forests is highly intermittent, that is, large fluctuations in air motion occurring in only brief periods and separated by longer quiescent periods of one to several minutes (Shaw 1985). Fig. 4 showed the difference between Kurtosis for

Gaussian distribution and that of our *u, v,* and *w* velocity components. The Kurtosis values of all components for all runs were much greater than 3 and than that of the results by Lee and Black (1993). The airflow near forest floor was characterized by high intermittence.

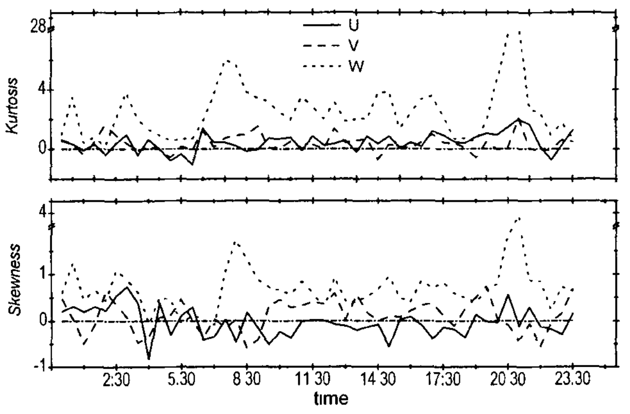

Fig. 4 Daily patterns of Skewness and Kurtosis near forest floor of a mixed broad leaved/Korean pine forest

Time scales and length scales

Time scales and Length scales were indicators for duration and spatial structure of turbulence eddies. We calculated Eulerian time scales for *u, v,* and *w* by integration of the autocorrelation function (Amiro and Davis 1988; Amiro 1990). The very low mean velocities and high turbulence intensities within forest canopies imposed conditions where Taylor's 'Frozen eddy' hypothesis does not hold, and length scales based on *u* are no more meaningful than those based on the standard deviations (Amiro 1990). Following Amiro (1990), We define Length scales near forest floor as $L_{u,v,w} = \sigma_{u,v,w}T_{u,v,w}$, where $\sigma_{u,v,w}$is the standard deviations for u, v, w components, $T_{u,v,w}$ is time scales. Result was listed in Table 3.

Table 3. Averages of time scales and length scales of *U, V,* and *W*

Items	Time Scales(s)		Length Scales (m)	
	Daytime	Nighttime	Daytime	Nighttime
u	7.8	38.9	4.4	8.7
v	22.4	49.9	13.0	10.1
w	3.3	7.9	0.6	0.6

According Table 3, time scales and length scales of vertical components were much smaller than that of horizontal components. Turbulence eddy near forest floor looked like a 'Disk'. During daytime, airflow is in the mixed convection state, both wind shear and buoyancy controlled turbulence near forest floor; while, during nighttime, wind velocity calmed, and buoyancy become the dominant factor. Time scales during nighttime are much larger than that of daytime, but for the reduction of turbulence density during night, the length scales increase a little or hold or even reduce.

Conclusions

The airflow near forest floor is characterized by high intermittence and asymmetry, and the active and upward movement takes the leading position. Vertical turbulence is retained and its time scale and length scale are much less than that of *u, v* components near forest floor. The eddy near forest floor shows a flat structure and look like a 'Disk'. Buoyancy plays a leading role in generation and maintenance of local turbulence.

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